100x100 CID IMAGER WITH INTEGRATED FIXED PATTERN NOISE SUPPRESSION

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ABSTRACT

Area imagers with xy-addressing schemes like photodiode arrays or charge injection devices (CID) are limited in dynamic range by fixed pattern noise (FPN), not by random noise. A novel, fully integratable differential readout method giving high FPN suppression and thus a high signal-to-noise ratio was implemented with a CID imager with 10000 picture elements. A FPN-suppression of two orders of magnitude was measured.

INTRODUCTION

Experiments with solid-state imagers started with xy-addressed imagers in thin-film technology employing photo resistors as picture elements. Also the monolithic integrated imagers to follow still utilized xy-addressing schemes /1/. All of those imagers were unsatisfactory in their signal-to-noise (S/N) ratio because of their high fixed pattern noise. This FPN can be reduced by technological means and use of integrating readout techniques, but is still the dominant noise for existing xy-addressed imagers like photodiode arrays /2/ or charge injection devices (CID) /3/.

Only with the invention of the charge coupled devices (CCD) this problem could be solved. These imagers, however, exhibit blooming along the CCD-channels, smearing (frame transfer principle) and consume a larger area than CID imagers. This paper presents a synthesis between both approaches combining their advantages. For the first time an integrated differential readout technique eliminating the additive FPN is presented.

OPERATION PRINCIPLE

Noise sources in xy-addressed imagers can be classified into three groups. First there is noise proportional to the signal caused by variations in in the sensitivity of the sensor elements. Next there is additive fixed pattern noise caused by local variations in the clock feedthrough during the readout operations and by local dark current variations. These noise sources stem from nonuniformities in the technological parameters such as oxide thickness, line width, substrate doping etc. Finally there is random noise consisting mainly of the reset (kTC) noise of the column and readout lines. The dominant noise is the additive FPN caused by clock feedthrough variations. To eliminate this FPN a differential readout technique is used where first the disturbed signal of one row is read out and temporarily stored, then the FPN alone ("zero signal"). In a differential stage the undisturbed signal is restored by subtraction of the FPN from the disturbed signal.

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IMAGER

One way of realizing a temporary memory is the use of two CCDs, one for readout and storage of the disturbed signal, the other one for the FPN. Fig. 1 shows schematically the organization of the 100x100 CID imager with integrated FPN suppression. The light sensitive part consists of pairs of MOS-capacitors forming the picture elements. These are indicated by their electrodes and the surface potential wells. The hatched region of the potential wells is a measure for the signal charge stored. One electrode of each element is connected to a row line, the other to a column line. For readout first one row line is selected via a digital shift register. The signal charge, which is held under the row electrodes during integration time, now flows under the column electrodes. The column lines are left floating during this operation, therefore a voltage drop proportional to the signal charge occurs on the column lines. Now charge is transferred from the column lines via TG1 into the CCD elements until this voltage drop is removed, which is the case when a charge packet of exactly the size of the signal charge has been transferred. The transistors TG1 cannot be operated simply as switching transistors because the large capacitance of the column lines and the small capacitance of the CCD elements would cause the CCD to be swamped with charge carriers /4/. By operating the transistors in the saturation region it is possible to transfer only the signal charge in much the same way as in a bucket brigade device. Threshold voltage variations of the transistors TG1 lead however to the transfer of additional variable quantities of charge which appear in the signal in the form of FPN. This noise can be avoided with a modified design enabling the reset of the column lines via TG1 before each readout operation /5/. In the next step the charge is moved from CCD1 into CCD2 as described in /6/. Now the picture elements of the selected row are reset by charge injection into the substrate. Immediately thereafter the same row line is selected again and a zero signal, i.e. only the FPN is read out into the inner CCD as described above. Both CCDs are clocked out synchronously. Their outputs are connected to a differential stage, where the FPN is removed from the signal. In this case an external differential amplifier was used, but integration of a differential stage on the sensor chip is possible.

EXPERIMENTAL RESULTS

Fig. 3 shows the output signal of one row of the 100x100 imager with one picture element illuminated before and after signal processing. The maximum signal is 500 mV and the signal-to-noise ratio -6 dB before the differential stage. That means the FPN is twice as high as the signal voltage. After the differential stage a S/N ratio of 40 dB was measured. Fig. 4 shows a picture taken with this imager.

The efficiency of this differential readout method is limited by nonlinearities in the readout operations and differences between signal and FPN readout. With the set-up used the limit was given by insufficient transient behaviour of the pulses from the external TTL clocking circuitry. Calculations show, however, that the limit with ideal pulses is given by the nonlinearities of the CCD output stages, which are caused by the signal dependence of the pn-junction capacitance. The FPN suppression is limited to 60 dB by this effect for the described imager.

CONCLUSION

The closest limit for the dynamic range of xy-addressed solid-state imagers is given by fixed pattern noise. For the first time an integrated solution to this problem was presented on the example of a 100x100 CID imager. A S/FPN-ratio of 40 dB was achieved. With a slightly modified readout operation giving less FPN before signal processing the FPN can be made lower than the thermal random noise. This differential readout technique can also be applied to other xy-addressed imagers, e.g. photodiode sensors.

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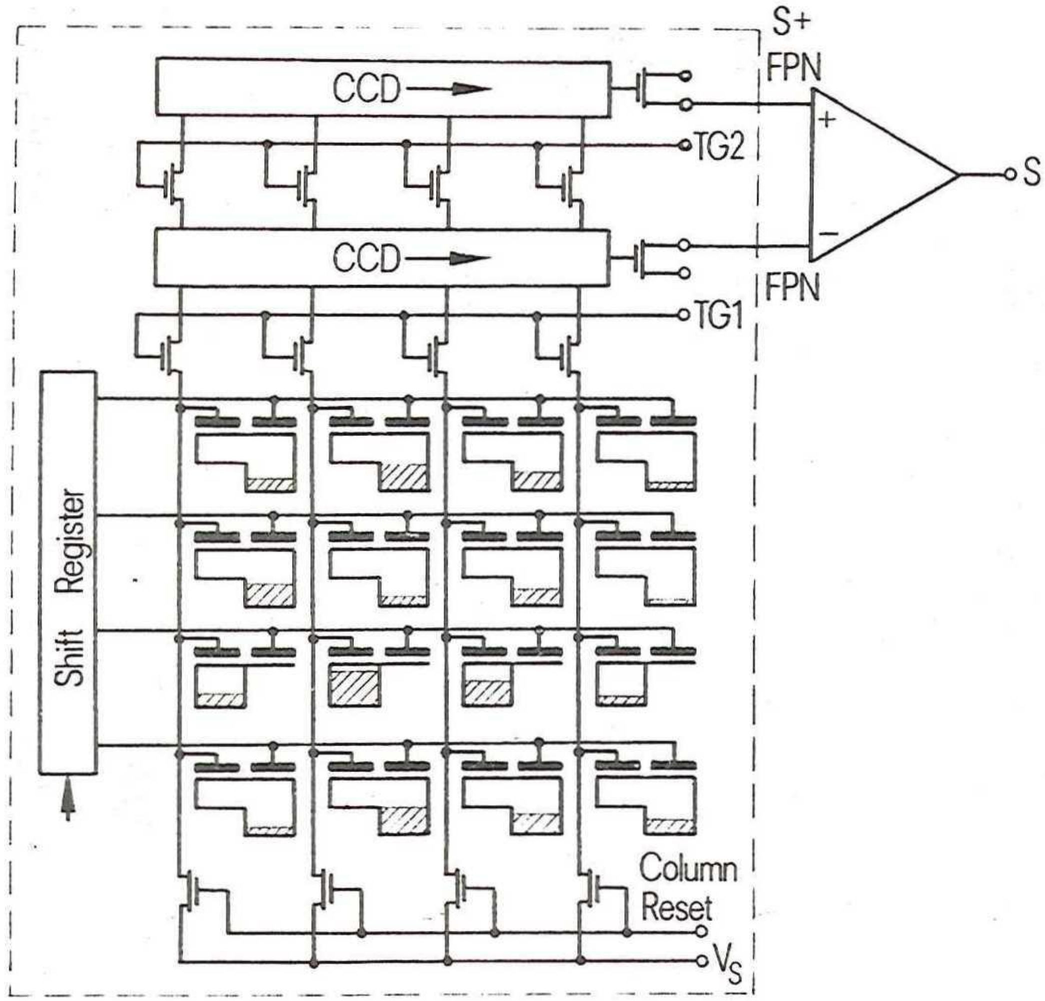

Figure 1. CID imager with integrated FPN suppression

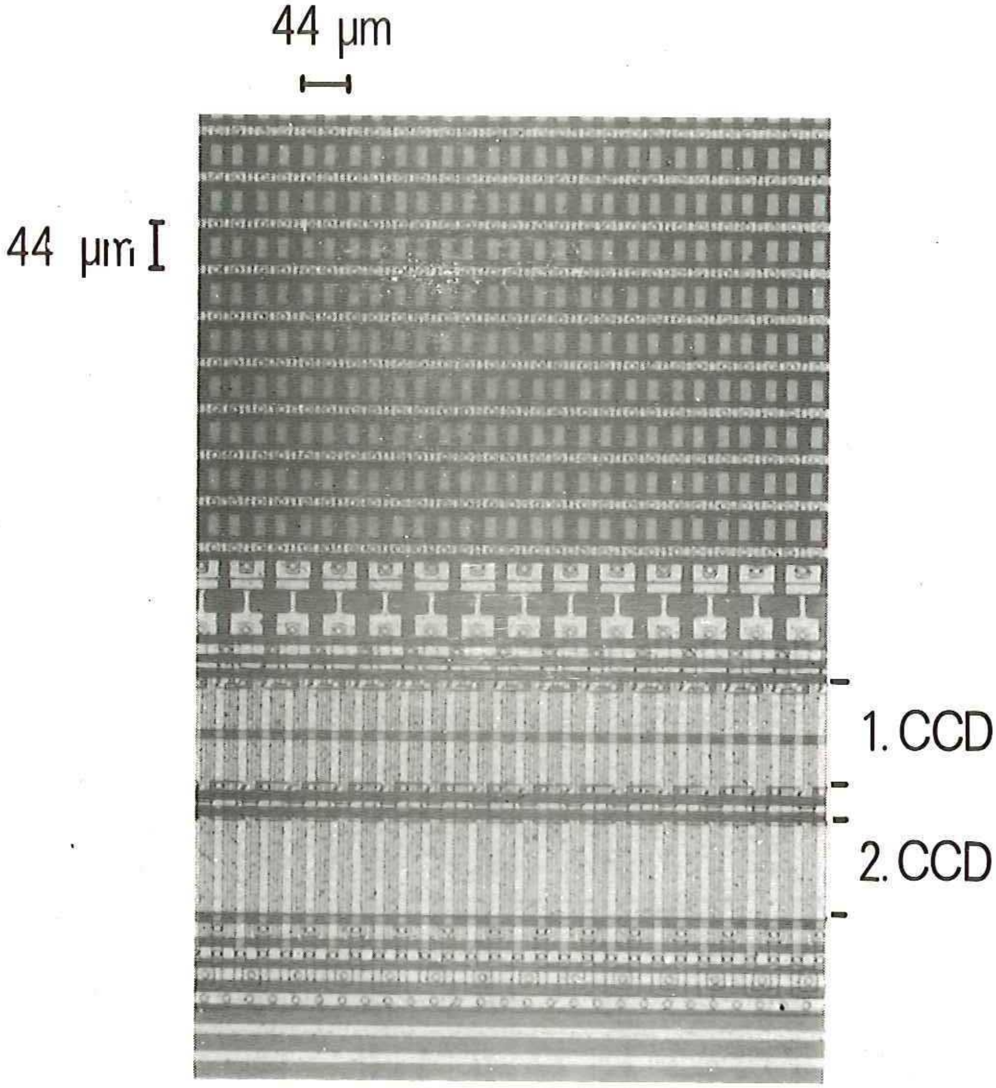

Figure 2.

CID imager with two readout CCDs

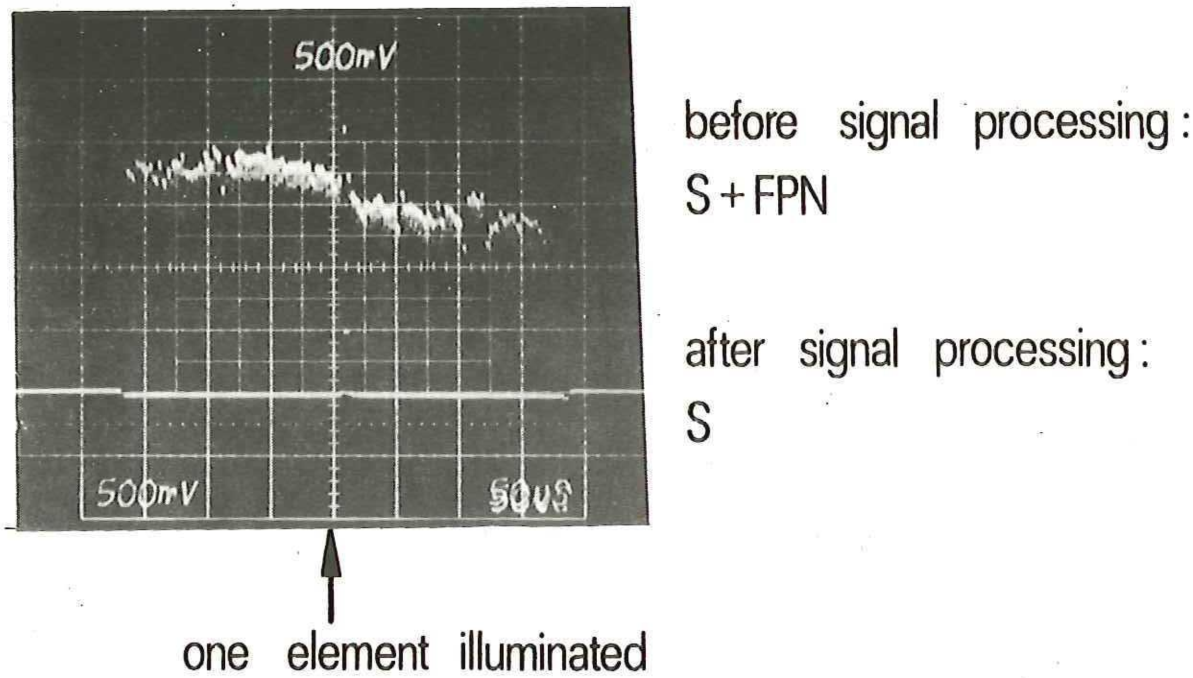

Figure 3. Output signal of one row of 100 × 100 CID imager

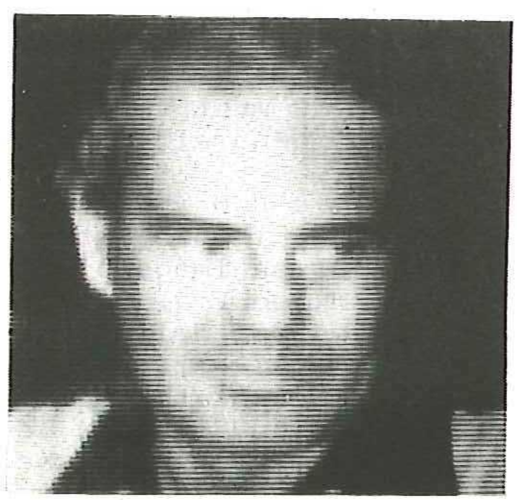

Figure 4. Picture taken with 100 × 100 CID